ELECTRICAL PROPERTIES OF SOME BUILDING MATERIALS

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Abstract

Electrical properties of materials are utilized in many areas of human activities and most frequently are applied at the moisture content measurements. Estimates of water content from electromagnetic wave measurements make use of the large relative permittivity of water compared to other material components. Our measurement were done on building bricks and sandstone bricks form Department of Materials Engineering and Chemistry (Faculty of Civil Engineering, Czech Technical University in Prague) on the base of International project of scientific cooperation. We measured resistance, impedance and capacitance of these materials. Frequency dependencies of the electrical properties at various moisture contents were constructed.

Key words: electrical properties, building materials

Introduction

Electrical properties of porous materials are influenced by the characteristics of the air, which is trapped in the pores, most especially its relative humidity and temperature. Among the influential factors for porous materials, the following can be named: size and distribution of pores, porosity and bulk density. Further factors are temperature of the material, but the most significant is the influence of the presence of water, its uneven deployment in the material, different binding energy in each water bond in the material and sorption properties (Hlaváčová, 1994).

Electrical properties of materials are utilized in many areas of human activities and most frequently are applied at the moisture content measurements. Estimates of water content from electromagnetic wave measurements make use of the large relative permittivity of water compared to other material components. Relative permittivity of dry material components are from 3 to 7 for mineral components, 2 to 5 for organic material, 3 for ice and for liquid water at 20 °C and frequency $f = 1$ GHz is $\varepsilon_r = 80$ and at $f = 10$ GHz is $\varepsilon_r = 64$. Measurement of electrical properties is quick and relatively simple. These properties are used at the estimation of other characteristics of building materials too.

For example a sensor system, which allows discretised electrical measurements within the cover concrete (covercrete), was utilised to study both the short- and long-term depth-related response of the covercrete subjected to a range of exposure conditions (McCarter et al., 2005). The system can provide information on the electrical conductivity of concrete through the coverzone, this parameter being important once the steel is depassified.

Application of TDR measuring technique for monitoring moisture content in hygroscopic building materials was investigated by Pavlík et al. (2005). They found out that the calculation of their moisture content from measured relative permittivity used in soil science is not possible in general, and verification of conversion functions and mixing formulas by a reference method is necessary case by case. A microwave impulse method is employed to the monitoring of residual moisture content in early hydration stages of cement paste (Pavlík et al., 2003).

The dielectric properties of mineral building materials in dependence on salt and moisture content are best characterised by the mixing model (Leschnik and Schlemm, 2001). They found out that at a frequency of

2.45 GHz the real part of the permittivity hardly depends on the salt content. They used mixing formula for the permittivity of the system of water and dry porous material

$$w = \frac{\sqrt{\varepsilon'} - \sqrt{\varepsilon'_m}}{\sqrt{\varepsilon'_w} - \sqrt{\varepsilon'_m}} \tag{1}$$

where: w - moisture content, ε' - the resulting permittivity, ε'_w - permittivity of (free) water, ε'_m - permittivity of the dry material.

Measurements of resistivity, impedance and capacitance of bricks and sandstone bricks are described in this paper.

Material and method

Our measurement were done on building bricks and sandstone bricks from Department of Materials Engineering and Chemistry (Faculty of Civil Engineering, Czech Technical University in Prague) on the base of International project of scientific cooperation. The masses of dry building bricks were: m_1 = 4.05 kg, m_2 = 3.76 kg, m_3 = 3.78 kg, m_4 = 3.767 kg and for sandstone bricks m_5 = 5.79 kg, m_6 = 5.646 kg, m_7 = 5.94 kg.

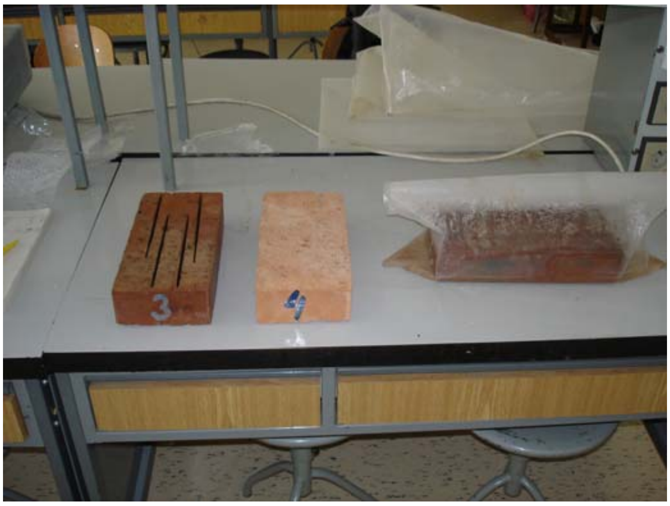

Fig. 1: Wet brick No 3 with channels, dry brick No 4 and brick No 2 wetted in closed carry bag

The bricks were wetted in closed carry bag 8 months to achieve saturated moisture content.

Bulk density of dry bricks was from 1 600 kg.m^{-3} to 1 915 kg.m^{-3}. Wet bricks have bulk density from 2 030 kg.m^{-3} to 2 183 kg.m^{-3} at saturated moisture.

Electrical properties were measured at various frequencies after various times of bricks storage on air. Electrical resistance, impedance and capacitance were measured by LCR meter GoodWill LCR-821 at frequencies 100 Hz, 500 Hz, 1 kHz, 3 kHz, 10 kHz, 50 kHz, 100 kHz and 200 kHz. Measurement setup is on Fig. 2. We used two copper plates with dimensions 5 cm x 5 cm. Three values of every electric parameter were measured out at each frequency and from measured value were calculated the average values of resistance, impedance and capacitance.

Fig. 2: Measurement setup

Results

Frequency dependencies of the electrical properties were constructed. For example, on Fig. 3 frequency dependency of resistance for the sandstone brick No 5 at two masses $m = 6.54$ kg (o) and $m = 6.44$ kg (+). Distance of the plates was 4 cm. This brick was dried 4 days on the air. The mass of water lose was 0.1 kg. Moisture of brick decreased and the resistivity is lower on whole measured frequency range.

Regression equation has power shape

$$R = R_0 \left(\frac{f}{f_0} \right)^{-k} \tag{2}$$

where: R – resistance, R_0 – reference resistance, f – frequency, f_0 = 1 kHz. The regression equations for impedance and capacitance have the same shape.

Tab. 1: Coefficient of regression equation and coefficient of determination for Fig. 3

m , kg	R_0 , kΩ	k	R^2
6.54	4.01752	0.0403815	0.821402
6.44	6.95733	0.0833372	0.961051

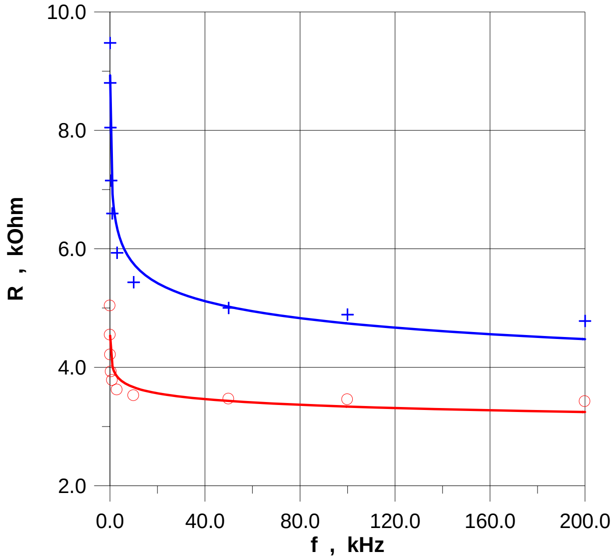

Fig. 3: Frequency dependency of the resistance for sandstone brick No 5 at two masses of brick (*m* = 6.54 kg, *m* = 6.44 kg)

On Fig. 4 frequency dependencies of the impedance for two bricks (No 2 - o, No 3 - +) are shown. Building brick No 2 has saturated moisture content and its impedance is lower in whole frequency range, brick No 3 was put two days on the air and loosed about 4.2 g water. Impedance of all samples decreases with frequency powerly too.

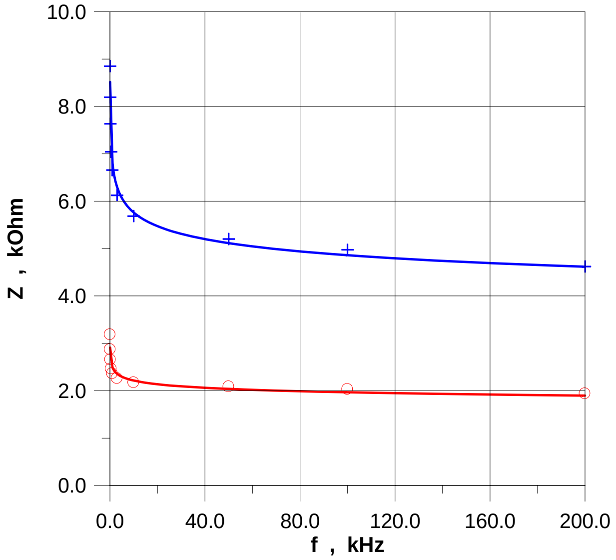

Fig. 4: Frequency dependency of the impedance for two bricks (No 2 with saturated moisture, No 3 after two days of natural drying on the air)

Coefficients of determination for these dependencies have high values. We compared the dependencies for resistance and impedance for all samples. These dependencies have the same shape and differences are negligible. It is visible on the Fig. 5 for sandstone brick No 5. It is evident that in this frequency range the reactances of bricks haven't influence on their impedance.

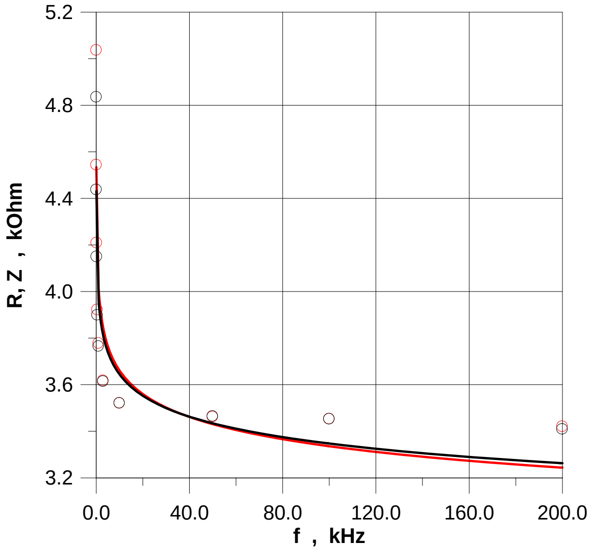

Fig. 5: Frequency dependency of the resistance (red) and impedance (black) for sandstone brick No 5 at $m = 6.54$ kg

On Fig. 6 the frequency dependencies of capacitance for two bricks No 2 and No 3 are made. The brick with saturated moisture content has higher values of capacitance. The regression equation has similar shape as Eq. (2). Capacitance changes from 0.02 nF to 280 nF. The coefficients of determination have high values.

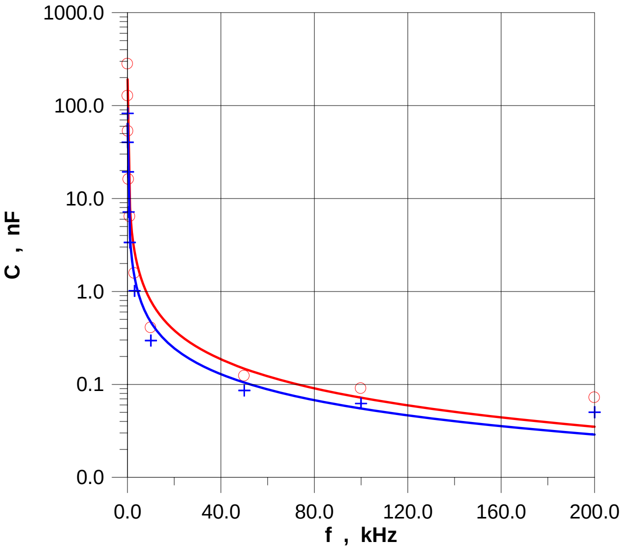

Fig. 6: Frequency dependency of the capacitance for two bricks (No 2 with saturated moisture, No 3 after two days of drying on the air)

On Fig. 7 the frequency dependencies of impedance for brick No 2 and sandstone brick No 5 are compared. The development of curves is similar for these materials and displacement is caused by various moisture contents.

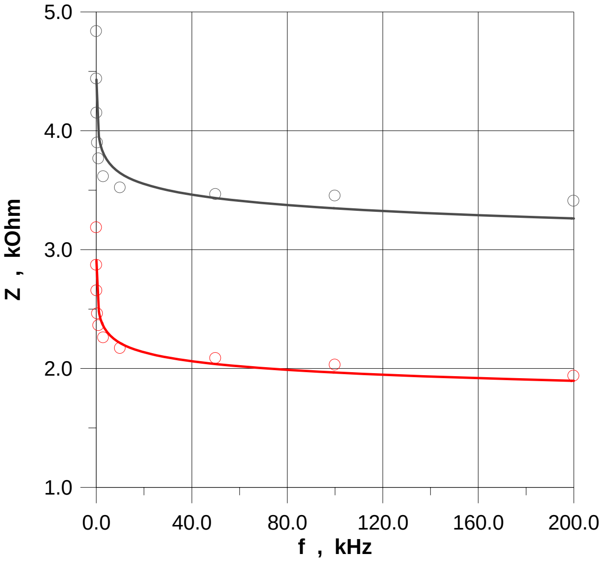

Fig. 7: Frequency dependency of the impedance for two bricks (brick n. 2 with saturated moisture, sandstone brick n. 5)

Conclusions

All measured electrical properties decrease with frequency powerly according to Eq. (2). These properties are influenced mainly by moisture content of bricks which is evident from Fig. 3, 4, 6 and 7. The dependencies for resistance and impedance for all samples have the same shape and the differences are negligible. It is evident that the reactance of bricks hasn't influence on their impedance in this frequency range. The resistance and impedance have lower values at higher moisture content. The capacitance has higher values in this case which is caused by properties of water. After finishing experiment and construction of dependencies on bricks moisture content this measurement can be applicable at the moisture determining.

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